Integrated modeling to manage south Florida's water resources

KENNETH C. TARBOTON & JAYANTHA OBEYSEKERA

South Florida Water Management District, 3301 Gun Club Rd., West Palm Beach, Florida 33406 USA

e-mail: ktarbot@sfwmd.gov & jobey@sfwmd.gov

Abstract Integrated water resources planning and management are critical in south Florida to enhance and restore natural flow and water levels to the unique Everglades system, while providing water supply and flood protection to the people of south Florida. In this paper integration of a system of multi-disciplinary models used in the development of the $7.8 billion Comprehensive Everglades Restoration Plan (CERP) is described. The alternative evaluation process, used in development of the CERP, is used to illustrate integrated evaluation of output and performance measures from different models for large- scale water resource planning in south Florida.

INTRODUCTION

The natural hydrology of south Florida has been altered through chanalization, urbanization and agriculture to the point where the Everglades original extent has been greatly reduced and it has become one of the most threatened ecosystems in the nation (Maltby and Dugan, 1994). The unique hydrology of south Florida, due to flat topography, high water tables, porous soils and high conductivity of the aquifer system, together with the extensive water control system now in place, makes the southern Florida water management system one of the most complex in the world.

The Central and Southern Florida (C&SF) Project which covers an area of 47,000 km^2 with

over 2800 km of levees and canals, 200 major water control structures and 27 pump stations, forms the backbone of current South Florida water management system (Fig. 1). Originally designed in the 1950's to provide for environmental and water supply needs of an expected population of two million by the year 2000, the C&SF Project can no longer effectively provide for environmental and water supply needs of the current population of around six million. The C&SF Project clearly requires modification to address Everglades restoration and the needs of the predicted 2050 population of twelve to fifteen million. Congress authorized a comprehensive review (Restudy) of the C&SF Project to determine changes needed to restore and preserve the natural ecosystem while improving water supplies and maintaining flood protection. Hundreds of scientists and professionals from more than 30 agencies and the private sector collaborated in the six-year Restudy that culminated in the Comprehensive Everglades Restoration Plan (CERP) presented to Congress in July 1999. The Plan, often described as the world's largest ecosystem restoration effort, has more than 60 major components designed to achieve a balance between ecosystem restoration and urban and agricultural water supply through better water management. Its fundamental goal is to capture and store most of the excessive fresh water that now flows to the Atlantic Ocean and Gulf of Mexico, and to deliver it when and where it is needed most. Once authorized by Congress, the plan will take more than 20 years to construct and will cost an estimated $7.8 billion, the cost being shared equally between the federal government and the state of Florida (U.S. Army Corps of Engineers and the South Florida Water Management District, 1999).

Development of the CERP relied heavily on the use of several hydrologic, ecological and water quality simulation models. The most important models used in developing the CERP are summarized in the following section, describing the processes simulated in each model and showing the

interdependence of the models. Thereafter, the alternative evaluation process is described, illustrating an approach to integrated multi-agency water resources planning.

MODELS

South Florida Water Management Model (SFWMM)

The South Florida Water Management Model (SFWMM, 1999) is an integrated surface water – groundwater model that simulates the hydrology and existing or proposed water management plans in the South Florida region using climatic data for the 1965-1995 period. The model simulates the major components of the hydrologic cycle including rainfall, evapotranspiration, overland flow, groundwater flow, canal flow, and seepage across levees. It also simulates the operations of the C&SF system components including major well-fields in the urbanized east coast, impoundments, canals, pump stations and other water control structures. The ability to simulate key water shortage policies affecting urban, agricultural, and environmental water uses allows the modelers to investigate trade-offs among different users and sub-regions. Two dimensional regional hydrologic processes are simulated at a daily time step using a mesh of 3.2 x 3.2 km (2 x 2 mile) grid cells producing extensive output that can be summarized into numerous performance measures for plan evaluation. The SFWMM is the premier hydrologic simulation model used to evaluate regional plans for Everglades restoration and sustainable development in South Florida.

Natural System Model (NSM)

The Natural System Model (SFWMD, 1998) attempts to simulate the hydrologic response of the pre-drainage Everglades using the same climatic inputs, daily time step, calibrated model parameters and algorithms as the SFWMM. The NSM differs from the SFWMM in that it does not simulate the influences of any man-made features and uses estimates of pre-subsidence topography and historical vegetation cover. Use of the same climatic input allows for meaningful comparisons between the response of the managed system, simulated with the SFWMM, to that of the natural (pre-drained) system, simulated with the NSM.

Everglades Screening Model (ESM)

The Everglades Screening Model is a mass balance model that simulates the major hydrologic features (primarily storages) and the demands of the South Florida water resources system (Fig. 1). It simulates most operating rules associated with major impoundments and water control structures using a weekly time step. The ESM is a valuable tool for ongoing water resources planning in South Florida because of its ability to evaluate water management components or alternatives in a relatively short time.

Everglades Water Quality Model (EWQM)

The Everglades Water Quality Model (Limno-Tech, 1995) simulates the fate and transport of phosphorus in the Water Conservation Areas and Everglades National Park (Figs 1 & 2). It uses a simple first order method to determine average phosphorus concentration and accretion rates within the SFWMM grid cells using rainfall phosphorus concentrations, phosphorus loading at the boundaries, and hydrological output from the SFWMM.

Lake Okeechobee Water Quality Model (LOWQM)

The Lake Okeechobee Water Quality Model is a single-segment eutrophication model that uses the Water Quality Analysis Simulation Program (Ambrose et al., 1993) modeling framework with enhancements (James et al., 1997) to simulate lake stage, volume, inorganic suspended solids, total phosphorus, total nitrogen, chlorophyll A and other water quality parameters. The LOWQM uses monthly average inflows, outflows, rainfall, and evaporation simulated in the SFWMM together with a time series of monthly nutrient loads and daily averaged water temperature and solar radiation.

Across Trophic Level System Simulation (ATLSS)

ATLSS is an integrated system of simulation models representing the biotic community of the greater Everglades region and the abiotic factors that affect this community (Institute for Environmental Modeling, 1999). The models are spatially explicit and have a resolution of 500 m x 500 m or finer. The abiotic processes simulated by the model are hydrology, fire and major storms. Presently, the ATLSS models are configured to use output from the SFWMM although it can be interchanged with any other hydrology model. The biotic modeling components integrate three approaches: (a) process models for lower trophic levels (including benthic insects, periphyton, and zooplankton), (b) structured population models for several important functional groups of fish and macroinvertebrates, and (c) individual-based models for endangered species or large consumers (Cape Sable seaside sparrow, wood storks, great blue herons, white ibis, American alligators, white-tailed deer, and Florida panther). The overall goal of the ATLSS models is to aid in understanding how the biotic communities of South Florida are affected by the hydrologic regime and other abiotic factors, and to provide a predictive tool for evaluating management alternatives.

Sub-Regional Models

A suite of high-resolution MODFLOW models (SFWMD, 2000) were applied to cover much of the urbanized coastal region of South Florida (Fig. 2). These models obtain boundary conditions from the SFWMM and are used for finer scaled analysis and detailed design of specific water management features. Each model has a horizontal spatial resolution of 500 ft and includes up to 8 aquifer layers. Enhancements developed specifically for South Florida hydrological conditions or existing packages applied in these model include; a wetland module (Restrepo et al., 1998), the modified lake package (Nair & Wilsnack, 1998), a trigger module to simulate water shortage policies, and a seepage return package to simulate levee seepage and return flow.

INTEGRATED ALTERNATIVE PLAN EVALUATION

Evaluation of water resources planning alternatives in South Florida is a complex, iterative process involving the integration of the above models through their interdependence (Fig. 3). The process used to select and refine a water management alternative for the CERP is described to illustrate integration of model data as well as an integrated multi-agency effort to evaluate model performance measures. Numbers in parentheses in the following paragraphs refer to numbered boxes in Fig. 3.

In development of the CERP, initial screening (1) was undertaken using the ESM to evaluate the individual feasibility of numerous possible water management features. A multi-agency alternative design team (ADT) formulated the initial and subsequent alternative plans (2) which were modeled using the regional-scale SFWMM (3). Performance measures that could be derived directly from the SFWMM hydrologic output were generated (5) and published (6) on a hydrological performance measures (HPM) web page (http://www.sfwmd.gov/org/pld/restudy/hpm). Output from the SFWMM was

used as input and provided boundary conditions for the Everglades Water Quality, Lake Okeechobee Water Quality, and ATLSS models (4) from which performance measures were also produced (5) and posted on the internet (6). Alternative plan evaluation was facilitated, and public involvement encouraged by allowing feedback and evaluation of alternatives via the HPM web page. Each alternative plan was evaluated by another multi-agency team called the alternative evaluation team (AET). The AET incorporated comments received from different agencies and the public, together with their own evaluation to make recommendations to the ADT for refinement (8) to improve performance in future alternatives. For each of seven alternatives, the above steps (2) through (8) were followed. An independent cost analysis was undertaken for each alternative and the preferred alternative selected (8) following a comprehensive evaluation of all the alternatives. The preferred alternative plan was used to define the CERP.

Development and continued refinement of performance measures formed an important part of the evaluation process. Conceptual ecological models were used together with the expert knowledge of the scientists on the AET to recommend measures for specific attributes that would indicate the "health" of the ecosystem. The Natural System Model was used as a measure of the best estimate of the pre-drained hydrologic response of the system. NSM hydrologic conditions were, in many cases, used as a targets for hydrologic restoration under the assumption that restoration of the hydrologic response that existed prior to drainage of the system would lead to restoration of natural habitats, biota and species. As better conceptual models become available, knowledge of the system improves and better versions of the NSM become available, performance measures will be further refined.

Refinement of the CERP is currently being undertaken through detailed design (9) and application of the sub-regional models (10). Boundary conditions, and structure flows for the sub-

regional models are derived directly from SFWMM simulated output. Following production (5) and publishing (6) of sub-regional performance measures, evaluation (7) will determine if refinements to the plan are needed (8). During refinement regional-scale modeling of the CERP will be undertaken to ensure region-wide performance of project features that may have changed through detailed design and modeling.

CONCLUSIONS

Comprehensive water resources planning for managing complex systems like the C&SF Project can be achieved most effectively via simulation models. The SFWMM is used as the key integrator and tester of current and proposed structural and operational components for major water resources projects in South Florida including development of the Comprehensive Everglades Restoration Plan. Ecological and water quality models use hydrologic output from the SFWMM to provide breeding potential for several species and quantify nutrient loading under different alternative management plans. Use of the internet to publish performance measures and assimilate feedback from multi-agency and stake-holder evaluation teams facilitated the integrated review and evaluation of alternative management plans. Sub-regional modeling, again using SFWMM output to establish boundary conditions and structural flows permits evaluation of more detailed design features as regional water resources plans are refined. Integrated modeling and multi-agency evaluation will continue in the future as the system evolves through implementation of project features.

Acknowledgement This paper summarizes the modeling efforts of many scientists and engineers in South Florida and elsewhere. The authors wish to acknowledge their contributions and apologize if any of their work has not been described adequately.

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FIGURE CAPTIONS

Fig. 1 South Florida water resources system

Fig. 2 Model domains for several south Florida models

Fig. 3 Integrated modeling process used in development of the Comprehensive Everglades Restoration Plan

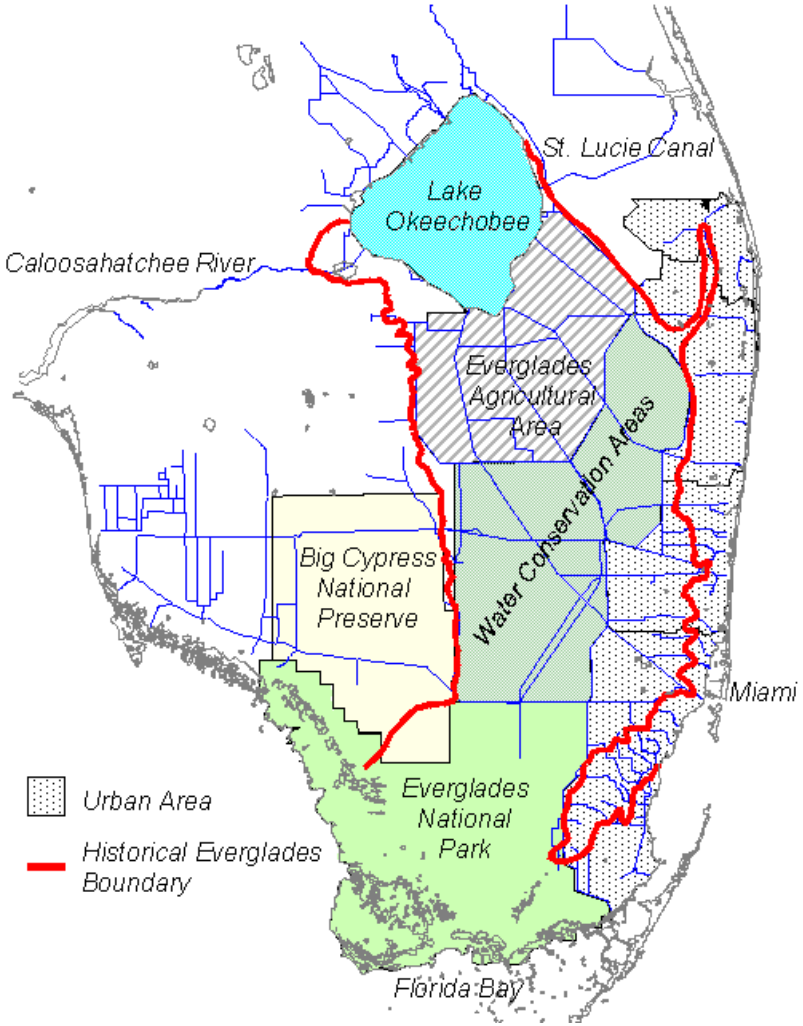

Fig. 1. South Florida water resources system

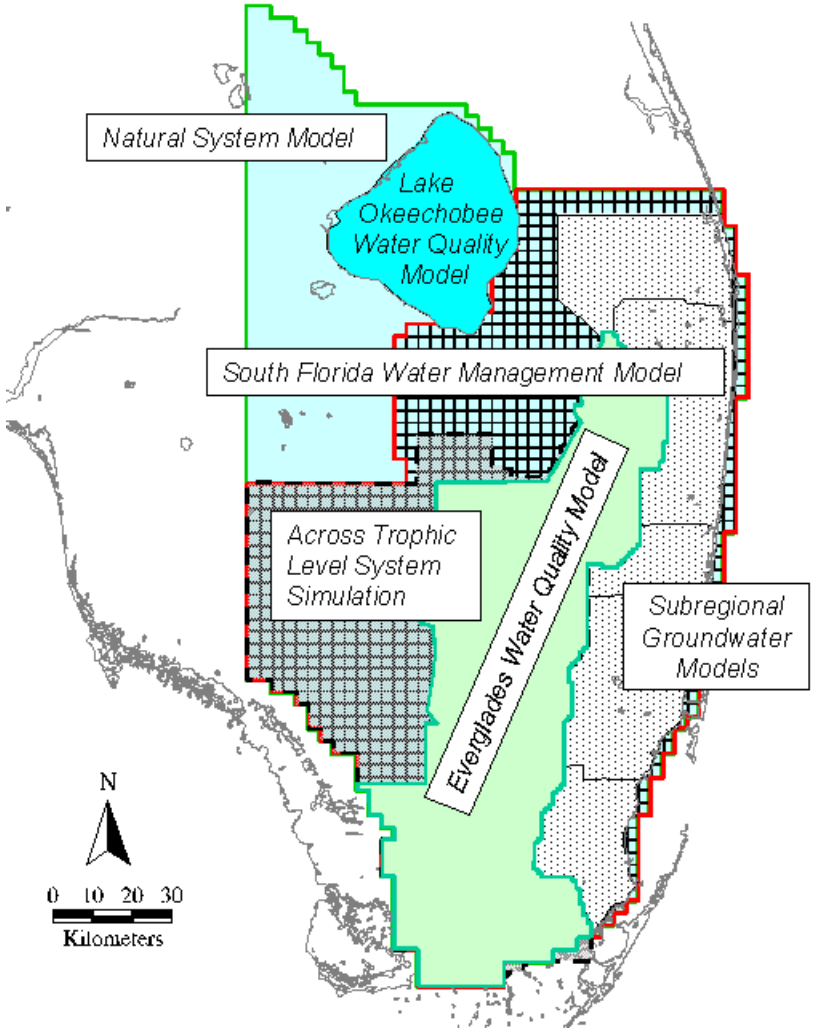

Fig. 2. Model domains for several south Florida model

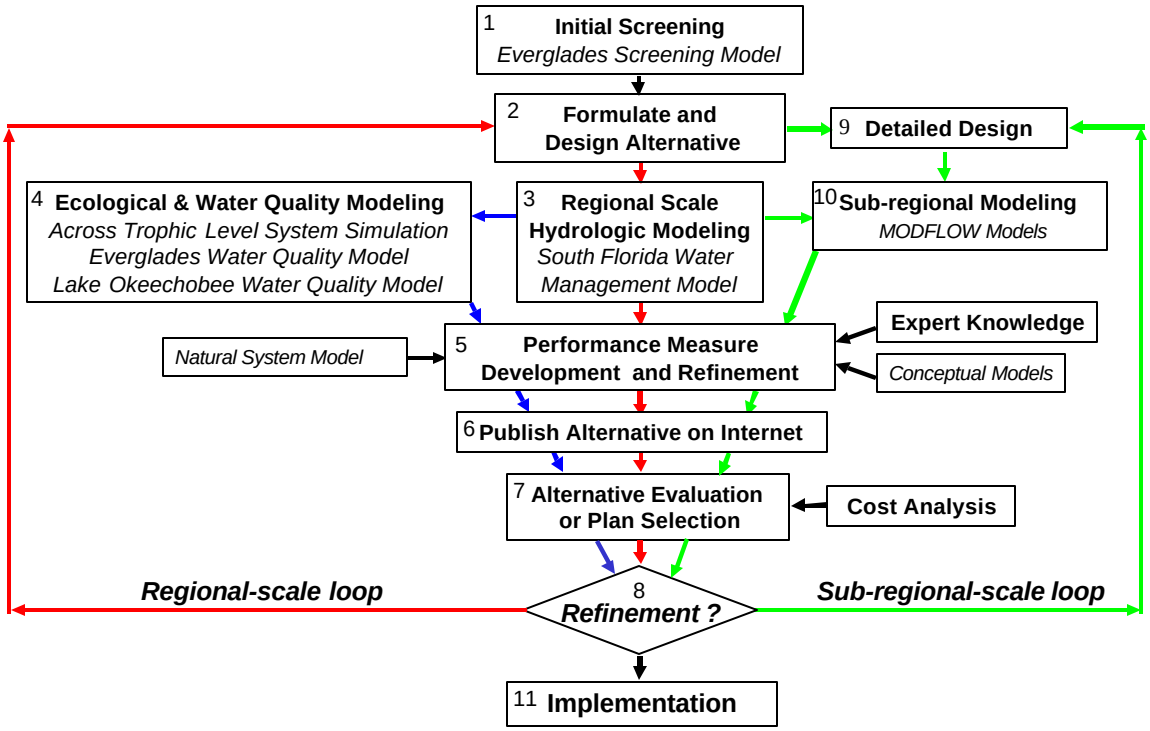

Fig. 3. Integrated modeling process used in development of the Comprehensive Everglades Restoration Plan